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Analysis of the meteorological synoptic situations that affect the Straits of Gibraltar and their influence on the surface wind

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ABSTRACT

The present paper describes a study of synoptic meteorological situations in the Strait of Gibraltar area. It is a well-established fact that, as a direct result of its topography, the surface winds at Gibraltar are usually easterly or westerly, and blow directly towards the end of the Straits, where the pressure is lower.

Therefore, a classification of 15 main major synoptic situations is proposed, based exclusively on surface pressure distribution, taking into account their respective frequencies from 1985-1990 according to the daily meteorological bulletins of Spain's Instituto Nacional de Meteorología.

The effect of each one of these synoptic situations on the resulting surface wind at the Strait is also analysed, using wind data recorded at the Planta Experimental Eólica de Tarifa (near Cadiz), from June 1987 to December 1989.

Key words: Strait of Gibraltar, synoptic meteorological situations, surface wind.

RESUMEN

Análisis de las situaciones meteorológicas que afectan al estrecho de Gibraltar y su influencia sobre el viento superficial

Se ha realizado un estudio particular de las situaciones meteorológicas sinópticas que afectan a la zona del estrecho de Gibraltar. Es un hecho conocido que, debido a la peculiar orografía del Estrecho, el viento superficial es casi siempre del Este o del Oeste y se dirige directamente hacia la zona del Estrecho donde la presión es menor.

Por este motivo se propone una clasificación en 15 situaciones meteorológicas basada exclusivamente en la distribución de presiones en superficie, contabilizándose la frecuencia de aparición de cada una de ellas durante el periodo comprendido entre los años 1985 y 1990. Para ello se han utilizado los Boletines Meteorológicos Diarios elaborados por el Instituto Nacional de Meteorología de España.

Posteriormente ha sido analizado el efecto que cada una de estas situaciones ejerce sobre el viento superficial resultante en el Estrecho, para lo cual se han utilizado los datos de viento medidos en la Planta Experimental Eólica de Tarifa (Cádiz), desde junio de 1987 hasta diciembre de 1989.

Palabras clave: *Estrecho de Gibraltar, situaciones sinópticas, viento superficial.*

INTRODUCTION

The influence of surface wind on the upper layers of the ocean is very well known. The effect of the special orography of the strait of Gibraltar on the surface wind is a well established fact, giving place to the typical prevailing easterlies and westerlies, with only very local cases of other wind directions.

Due to the effects of the Strait, and the fact that they are surrounded on both coasts (Spanish and African) by high mountain chains (Penibetic and Atlas, respectively), the wind that comes from the north or the south will be modified until it reaches a zonal direction– east (southeast-east-northeast) or West (southwest-west-northwest).

The easterly and westerly winds will be refreshed while passing through the Strait, as in a huge 'Venturi channel', in which, because of this narrowing, there is a noticeable increase in velocity, and a decrease in pressure, on the side of the Strait opposite to the wind direction (Bendal, 1982). But this minimum of pressure is not a consequence, but a prerequisite, of nearly horizontal motion (Scorer, 1952). This effect is more noticeable in easterly than in westerly winds, because of the greater narrowing on the eastern side of the Strait.

If the atmospheric stratification is unstable, the surface wind could be influenced by the upper winds, due to convective mixing. However, in the case of atmospheric stability –more frequent in the Strait, especially in summer– the surface wind blows directly from high to low pressures, crossing isobars with total independence of the upper flow.

Precisely because of this important relationship between the surface pressure distribution and the resulting surface wind, it is very important to know which synoptic meteorological situations are most frequent in this zone, and to study the particular effect of each one of them on the wind.

Different classifications of the atmospheric situations in Spain have been proposed (Castillo, 1981), but none of them can be adjusted strictly to our particular zone, because of all the reasons discussed above.

Therefore, a specific study of the Strait of Gibraltar was carried out, whose findings were used to establish 15 types of meteorological situations, based on the surface pressure distribution. Subsequently, the effect of each one of them on the surface wind was analysed.

MATERIALS AND METHODS

In order to elaborate the present study, surface pressure maps drawn up by Spain's National Meteorological from 1985-1990 were used.

The daily meteorological situation was analysed, taking into account the pressure systems that affected the Strait directly.

Naturally, there were many cases in which there was a coincidence of two or more systems, and each one of them was counted in order to elaborate a frequency table, based on the 15 situations chosen for our analysis, as well as another (designated P) when there was no a well-defined situation, due to a low pressure gradient.

Table I shows not only the total frequency, but also the monthly one for each situation, because it is very important to know the seasonal variation that takes place in the systems affecting the Strait. The total number of cyclonic and anticyclonic situations are also shown.

After drawing up this table, the effect of each situation on the local surface wind was carefully analysed using the wind data collected at the Experimental Power Plant located outside Tarifa (Cadiz), 2 km from the coast. The mast used has three levels of acquisition (10-, 20- and 30-m), with which 10-min average speed and mean direction were collected from June 1987 to December 1989.

These data were compared to the ones collected at the National Meteorological Institute mast, situated very near ours, just on the coast, and a very high correlation was found; therefore, the effect that local topography could exert on them was discounted.

Daily averages of these data were compared to the corresponding meteorological situations, enabling us to attain our main objective of analysing the effect of each one on the surface wind.

Shorter periods were also analysed, in order to evaluate the transition between the different meteorological situations, which are very useful for knowing the effect of each one of the pressure systems on the surface wind.

RESULTS

As noted above, a classification based exclusively on the surface-pressure distribution is proposed,

Table I. Table of frequencies

		Aa	A_N	A_{NW}	A_W	A_{SW}	A_S	A_E	A_{NE}	C_N	C_{NW}	C_W	C_{SW}	C_S	C_E	C_{NE}	A_{Total}	C_{Total}	P
January	%	17.1	0	0	28.5	11.4	2.8	0	2.8	2.8	11.4	2.8	0	0	11.4	2.8	62.8	34.2	2.8
February	%	5.5	2.7	16.6	19.4	0	5.5	5.5	2.7	2.7	2.7	16.6	8.3	5.5	2.7	2.7	58.4	41.6	5.5
March	%	8.1	2.7	18.9	35.1	0	5.4	2.7	5.4	0	0	0	10.8	0	5.4	5.4	78.4	21.6	5.4
April	%	2.1	0	2.1	31.9	2.1	0	6.4	4.2	8.4	0	0	0	34	2.1	4.2	48.9	48.9	2.1
May	%	2.1	0	4.2	22.9	2.1	0	6.3	0	8.3	6.3	6.3	0	29.1	6.3	2.1	37.5	58.3	4.2
June	%	0	0	3.7	7.4	0	0	3.7	1.8	11.1	11.1	1.8	0	40.7	14.8	1.8	16.6	81.5	1.8
July	%	1.7	3.3	11.7	10	0	0	6.7	11.7	13.3	0	0	5	23.3	5	6.7	45	53.3	1.7
August	%	0	0	10.1	10.1	0	0	5.8	10.1	20.3	1.4	0	7.2	24.6	0	10.1	36.2	63.7	0
September	%	0	14	4	10	0	0	10	12	6	0	0	20	16	2	4	50	48	2
October	%	5.1	0	7.7	17.9	0	0	5.1	12.8	0	10.2	2.6	15.4	12.8	2.6	2.6	46.1	46.1	5.1
November	%	5.7	11.3	1.9	5.7	0	3.8	5.7	15	0	5.7	18.8	5.7	9.4	5.7	3.8	49	49	1.9
December	%	11.1	11.1	22.2	6.6	0	4.4	8.8	13.3	0	0	6.6	2.2	0	0	13.3	77.7	22.2	0
Total		**4.1**	**4**	**8.3**	**15.8**	**1**	**1.5**	**5.5**	**8**	**7.1**	**3.8**	**4.3**	**6**	**17.9**	**4.6**	**5.2**	**48.4**	**49.3**	**2.2**

because this is the one that determines the main characteristics of the surface wind.

A classification based on 15 meteorological situations has been established, depending on the barometric regime (cyclonic or anticyclonic) and their relative position to the Strait:

1. Peninsular anticyclone (A_a) (figure 1): Originates when an anticyclone is settled just on the Peninsula.
2. North anticyclone (A_n) (figure 2): Anticyclone situated northside the Peninsula, usually very strong, exercising its influence up to the Strait.
3. Northwest anticyclone (A_{NW}) (figure 3): The same type as number 2, but the former's centre is moved westward; the latter is usually the Azores Anticyclone, moved northward.

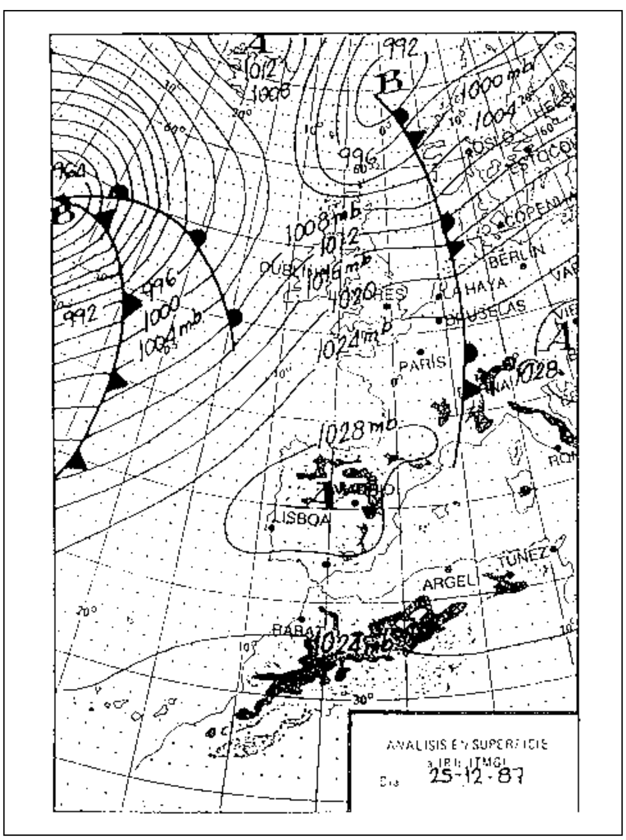

Figure 1. Peninsular anticyclone (A_a)

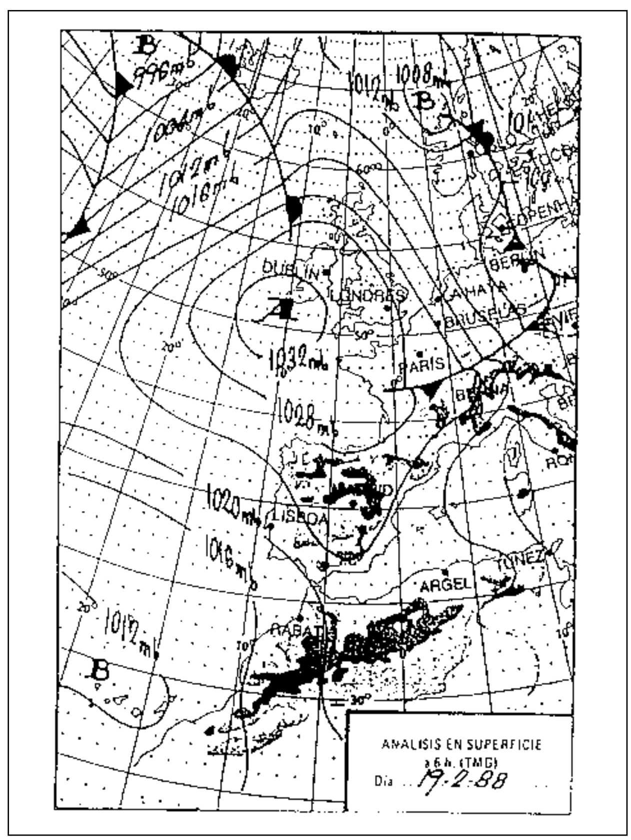

Figure 2. North anticyclone (A_N)

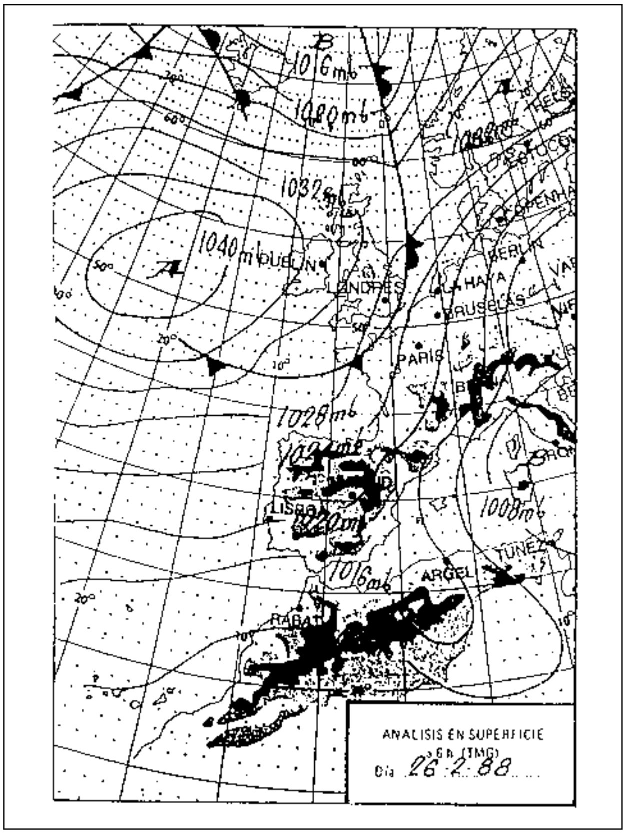

Figure 3. Northwest anticyclone (A_{NW})

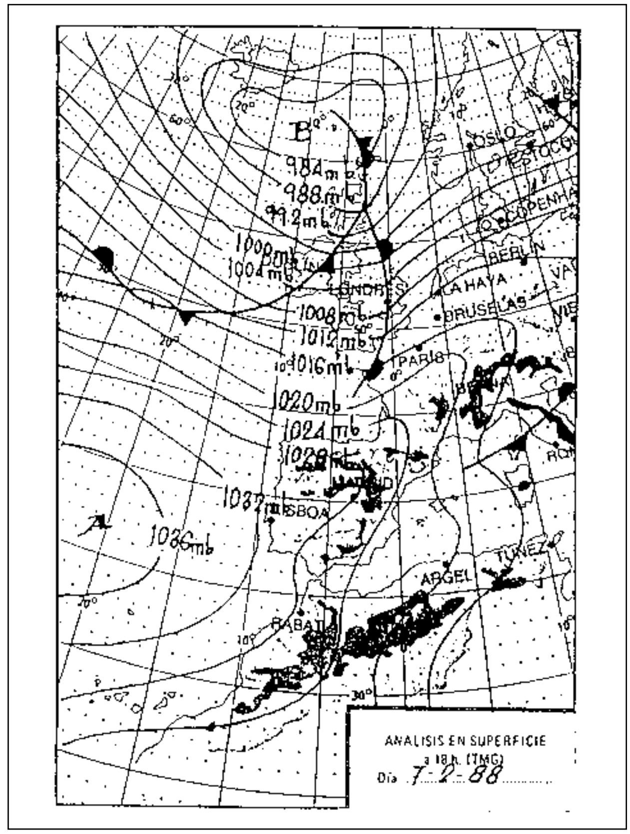

Figure 4. West anticyclone (A_W)

4. West anticyclone (A_W) (figure 4): Azores Anticyclone.
5. Southwest anticyclone (A_{SW}) (figure 5): Usually the Azores Anticyclone situated at low latitudes, although it can be a more local high pressure system.
6. South anticyclone (A_S) (figure 6): North African Anticyclone, which usually appears in winter because of the continental cooling.
7. East anticyclone (A_E) (figure 7): Typical summer Mediterranean Anticyclone, although it can sometimes appear in winter.
8. Northeast anticyclone (A_{NE}) (figure 8): It can be the Peninsular Anticyclone moved eastward, the Mediterranean one at the north side, or more commonly the European Anticyclone, which is very strong.
9. North cyclone (C_N): It could be the typical summer Peninsular Thermal Low (figure 9) –which replaces the winter Peninsular High– or a low centre crossing the Peninsula, or a northern low, near Britain. These two are usually joined to thermal fronts (figure 10). We could have separated the latter case from the two former ones, because the latitude is different, but we preferred to combine them because their influence on the wind at the Strait is similar.
10. Northwest cyclone (C_{NW}) (figure 11): It can be any one of the two last ones (8 and 9), moved to the west.
11. West cyclone (C_W) (figure 12): It is usually a low centre that crosses the Peninsula, which also usually carries thermal fronts (figure 13).
12. Southwest cyclone (C_{SW}) (figure 14): It can be a low centre situated at Cadiz Bay or near the Canary Islands, or just a westward displacement of the North African low centre. In the former case, it usually crosses the Strait with an associated southwest front.
13. South cyclone (C_S) (figure 15): Typical North African Thermal Low, which, as we shall see below, is very common, and not only in summer, as could be expected.

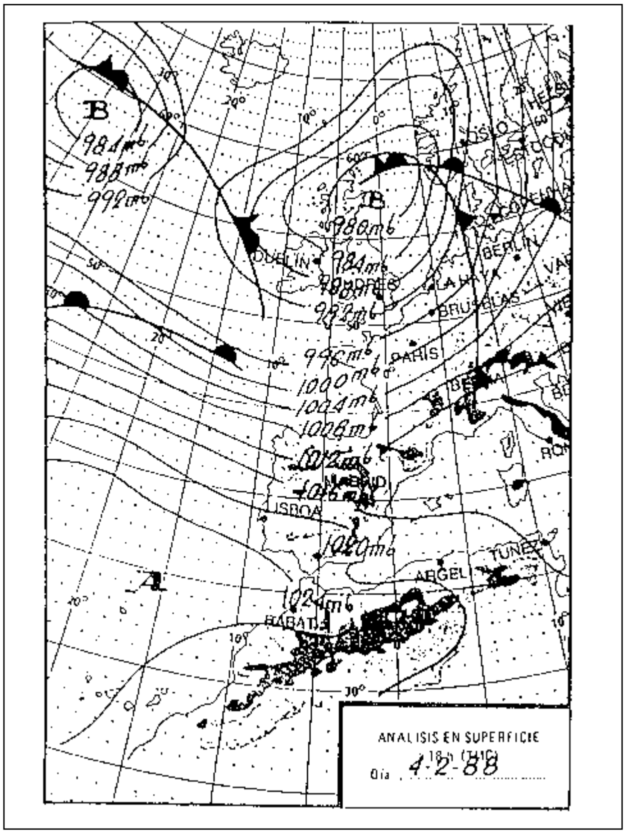

Figure 5. Southwest anticyclone (A_{SW})

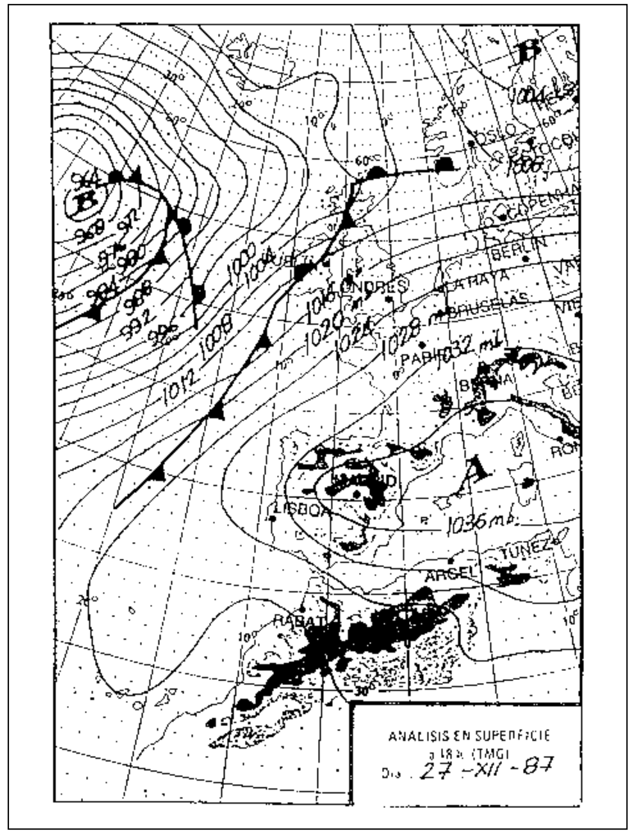

Figure 7. East anticyclone (A_E)

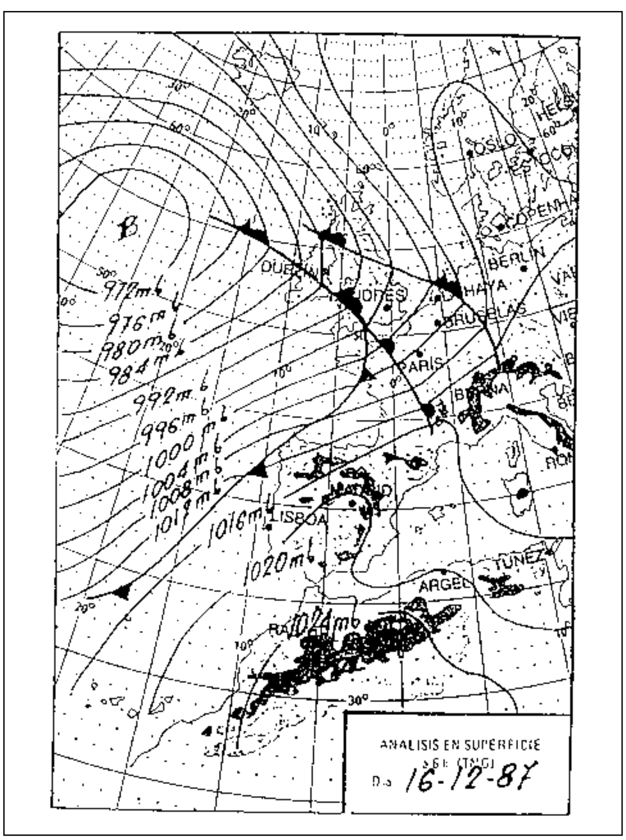

Figure 6. South anticyclone (A_S)

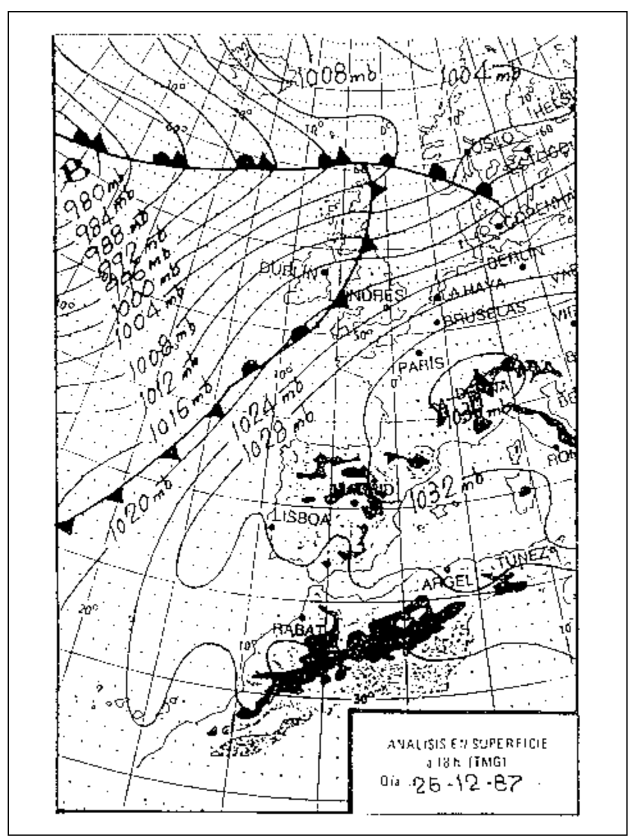

Figure 8. Northeast anticyclone (A_{NE})

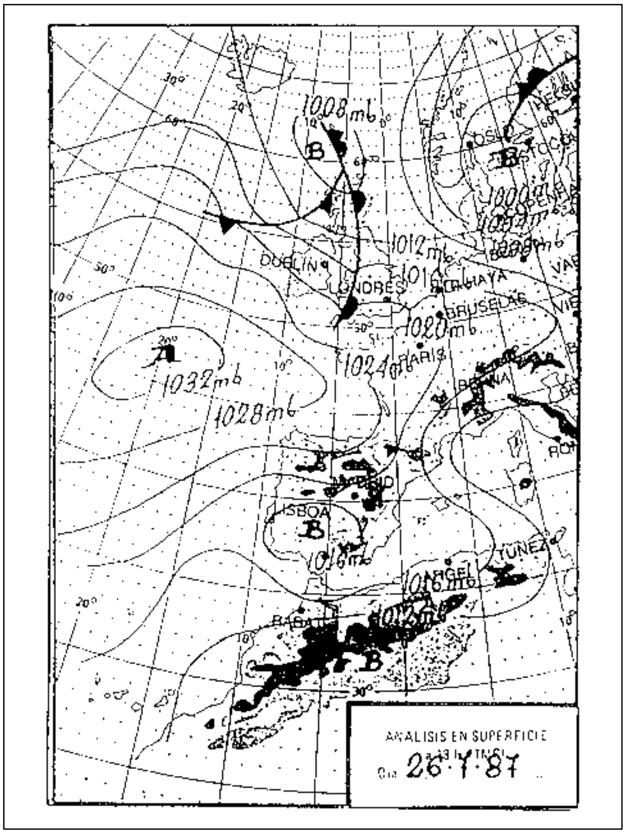

Figure 9. North cyclone (C_N)

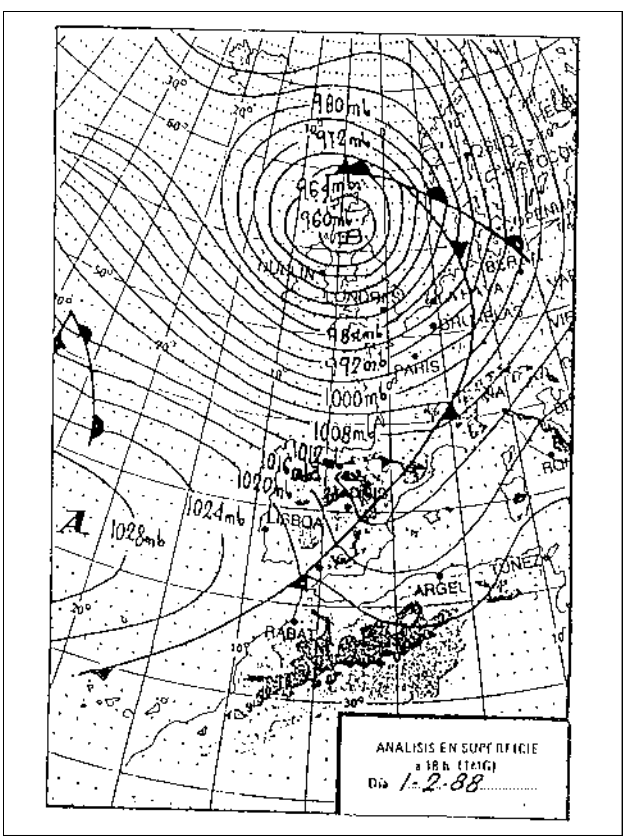

Figure 10. North cyclone with cold front (C_N)

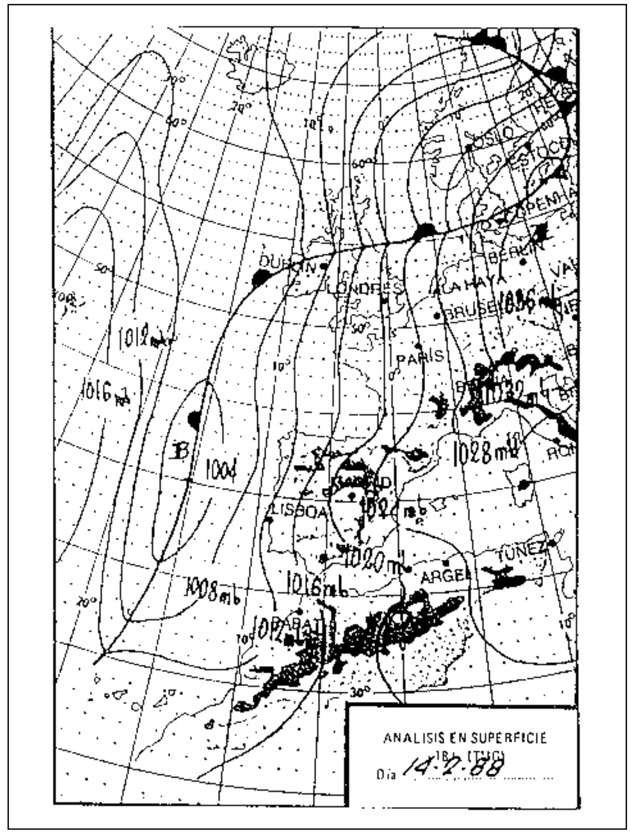

Figure 11. Northwest cyclone (C_{NW})

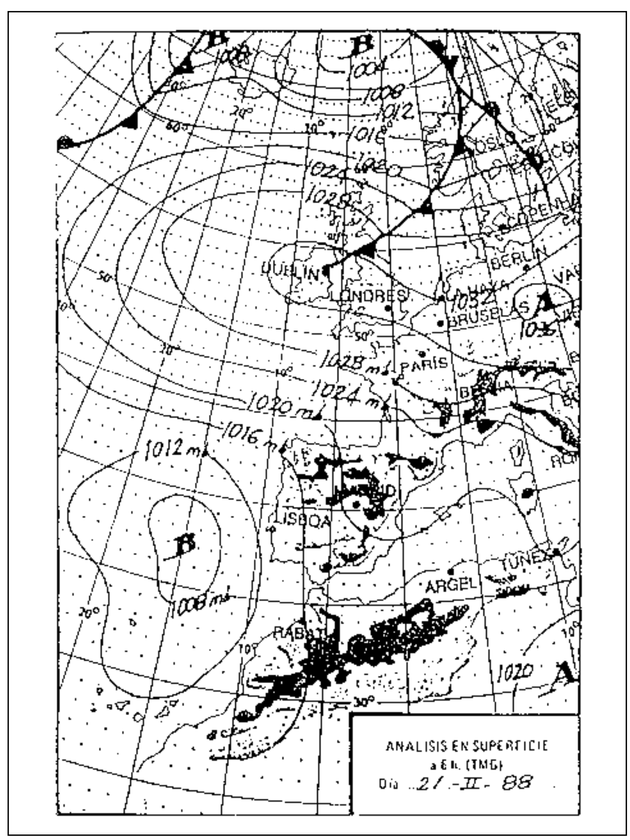

Figure 12. West cyclone (C_W)

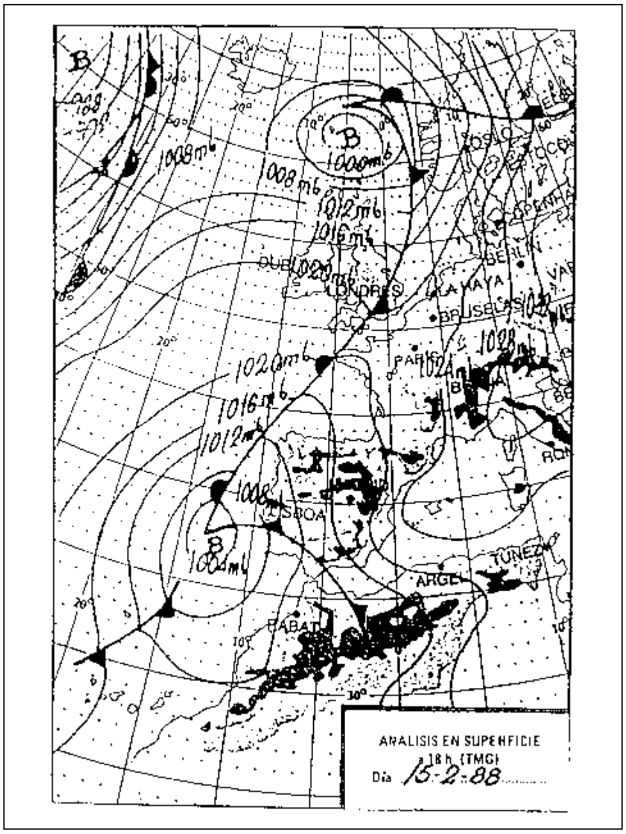

Figure 13. West cyclone with cold front (C_W)

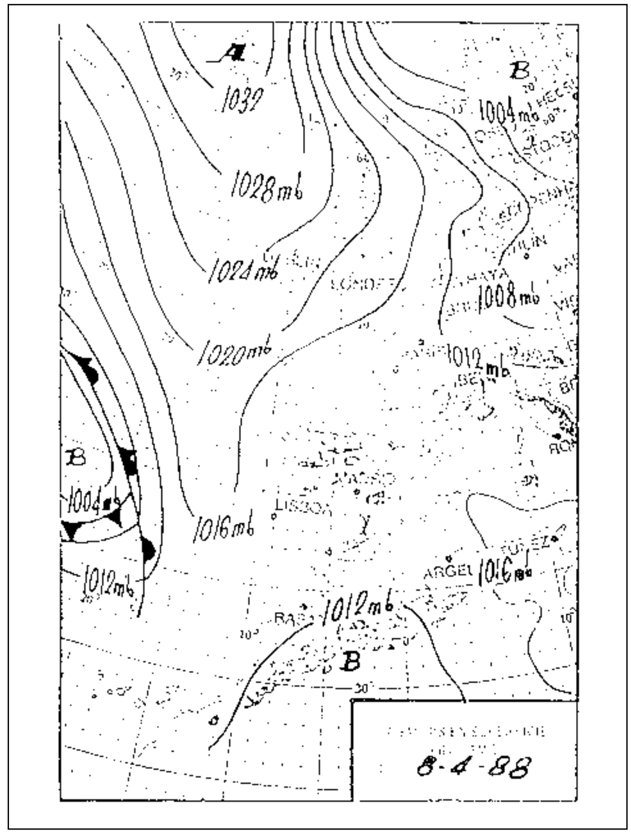

Figure 15. South cyclone (C_S)

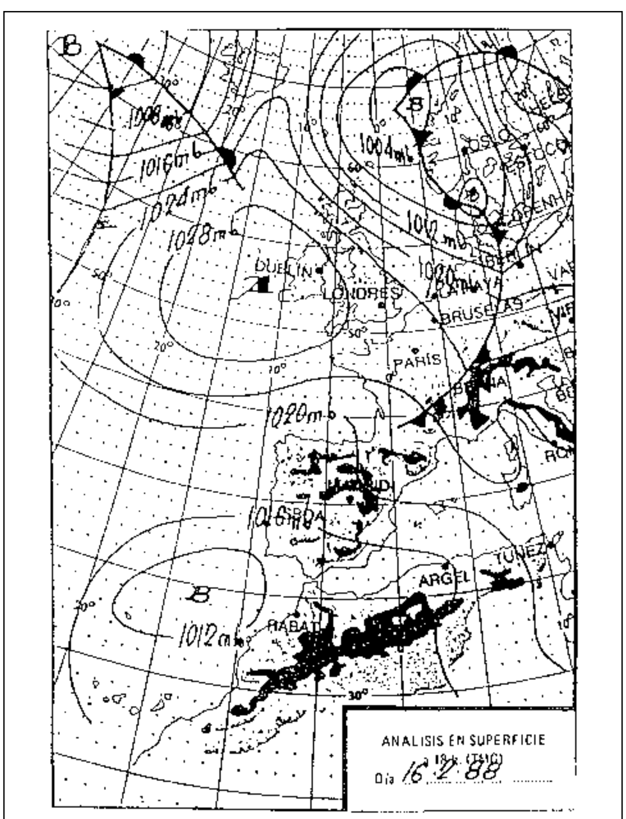

Figure 14. Southwest cyclone (C_{SW})

14. East cyclone (C_E) (figure 16): Typical Mediterranean Low, although it can appear any other time of the year.
15. Northeast cyclone (C_{NE}) (figure 17): Mediterranean Low situated northside, or the Thermal Peninsular Low at the east, or a low centre that has crossed the Peninsula.

Another, undefined situation (P), is added to the above15, when the situation is not very clear, because of the low pressure gradient.

Our main findings from this analysis of the different situations prevailing every month throughout the year, from 1985-1990 (frequencies shown in table I) are:

- Computing all the situations, the cyclonic ones (49.3 %) are nearly the same, proportionally, as the anticyclonic ones (48.4 %), with only 2.2 % of undefined situations (P).
- During the winter and mainly in the transition months between different seasons, the anticyclones prevail over the cyclones: January (A, 62.8 %), February (A, 58.4 %), March (A, 78.4 %) and December (A, 77.7 %).

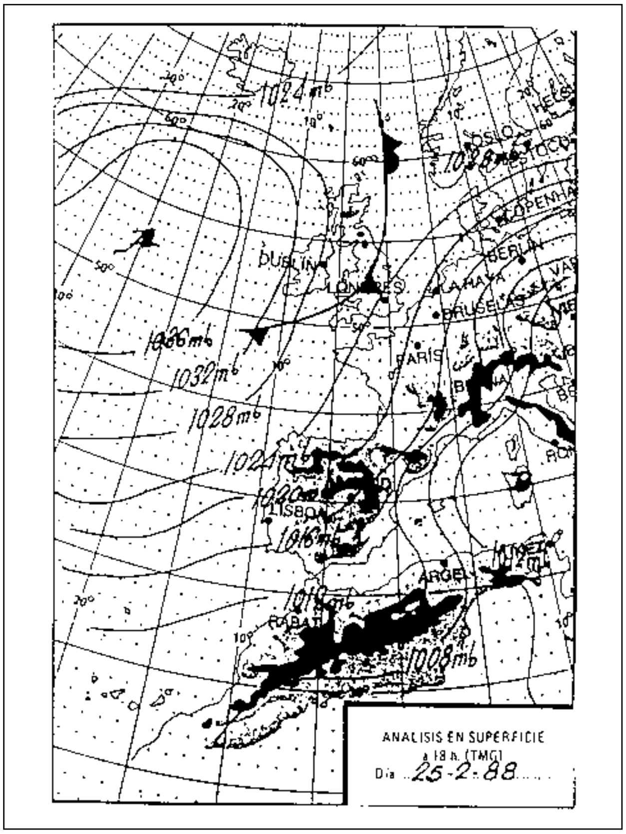

Figure 16. East cyclone (C_E)

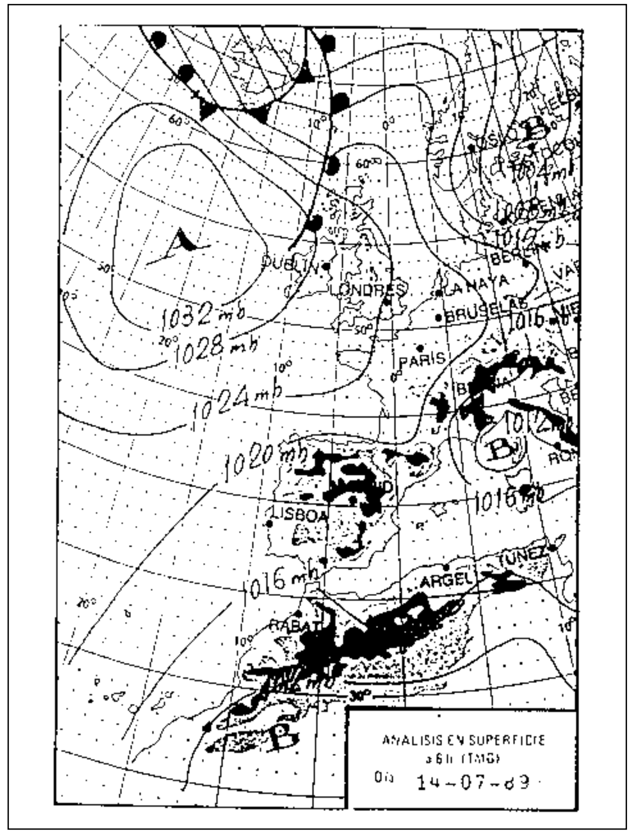

Figure 17. Northeast cyclone (C_{NE})

- In May (C, 58.3 %), June (C, 81.5 %), July (C, 53.3 %) and August (C, 63.7 %), i.e. in spring and summer, cyclonic situations prevail over anticyclonic ones, mainly due to continental warming, added to a movement of depressions across the Peninsula that is slightly higher than usual.
- In April (A and C, 48.9 %), September (A, 50 %; C, 48 %), October (A and C, 46.1 %) and November (A and C, 49 %), i.e., in the spring, and above all in the autumn, there are as many cyclonic as anticyclonic situations, because there is a change between the typical low pressures in summer and the high ones in winter.
- Among the anticyclonic situations, A_W (15.8 %) and A_{NW} (8.3 %) are very significant because the Azores Anticyclone is situated at the west and northwest of the Peninsula throughout the year. Between these two situations, the first one (A_W) is more common than the second one, except in July and December.
- Following these, A_{NE} (8 %) appears, originated by the establishment of a strong anticyclone at the centre of Europe –mainly during the last months of the year– or because of the Mediterranean Anticyclone situated on the northern side of this sea –typical in summer, in contrast with continental thermal lows. From January to June, it is infrequent. This Mediterranean Anticyclone also gives way to the A_E (5.5 %) situation, which appears sporadically throughout the year, but mainly in summer, because of the reasons noted above.
- The development of the Peninsular Anticyclone (A_a, 4.1 %) takes place mainly in winter, due to continental cooling, hardly ever appearing in summer.
- The development of an anticyclone on the northern side of the Peninsula (A_N; 4 %) is relatively common in autumn –from September to the end of the year– as is the European one (A_{NE}).
- Only during some days in January, April and May, the Azores Anticyclone is situated just to

the southwest of the Strait, or a smaller local anticyclone develops on this side (A_{SW}, 1 %).

- We can observe, on just a few occasions, a high centre that is situated to the north of Africa (A_S, 1.5 %), and these are only in autumn and winter, because during the spring and winter continental warming gives way to the development of the typical Saharan Thermal Low (C_S), as discussed below.
- Among the cyclonic situations, C_S (17.9 %) is very important, with its maximum in June and August.
- The C_N (7.1 %) situation is more frequent during the spring and summer, because it is related to the Peninsular Thermal Low, although it also appears in January and February due to the movement of depressions crossing the Peninsula, or at higher latitudes, typical of this time of the year. These low centres can also be found at the northwest (C_W, 3.8 %) or west (C_W, 4.3 %) of the Peninsula, mainly in January, February, October and November, May and June, because of the major variations observed in the jet-stream.
- In February, March, July, August, September, October and November, a low centre can appear to the southwest of the Strait (C_{SW}, 6 %), being very important in September (20 %) and October, causing the famous stormy easterlies.
- The Mediterranean Low centre (C_E, 4.6 % and C_{NE}, 5.2 %) has no special relevance at any particular time of the year. During the winter, it can have a thermal origin, but it can also be a low centre that has crossed the Peninsula.

  The low centres situated northeast of the Peninsula are also included in the C_{NE} situation.

  Finally, it is very interesting to note that during the period studied, between 30 and 40 thermal fronts crossed the Peninsula, and most of them did so in January and October, followed by February, April and May. Logically, these have no relevance during the summer, but we have to take into account that this number can vary from year to year, for the same month. However, the most important objective is to know how fronts can modify the wind conditions in the Strait.

After attaining our first objective, the classification of the different synoptic situations affecting the Strait, we assessed their corresponding influence on the surface wind.

The main findings of this assessment are summarised below.

The synoptic situations that give rise to eastern winds are:

- The Azores Anticyclone, when it is situated northwest of the Strait (A_{NW}), or a major anticyclone to the south of England (A_N) –when the isobars are parallel to the Strait, the wind also goes parallel to it. This is very frequent in autumn.
- The Mediterranean Anticyclone, situated either to the east (A_E) or northeast (A_{NE}) of the Strait, from which the air emerges, crossing the isobars. It usually appears during the summer, in contrast with the continental thermal lows, although it can appear at any time of the year.
- The European Anticyclone (A_{NE}), which is generally very large, and appears mainly in autumn and winter due to continental cooling. It usually originates winds from the northeast and east-northeast.
- The Peninsular Anticyclone (A_a), caused by the low winter temperatures (it also appears in autumn), when the isobars are parallel to the Strait.
- The winter North African Anticyclone, when it is moved to the east (A_E).
- The low centres situated to the west (C_W) or southwest (C_{SW}) of the Strait, and usually carry thermal fronts, appearing mainly in autumn, winter and spring.
- The North African Low Centre (C_S) when the isobars are parallel to the Strait. This situation is very common in summer, and above all in September.
- The Peninsular Thermal Low (C_N; C_{NW}), when the isobars are at a right angle to the Strait, or when its centre is moved to the west.

The situations that give rise to western winds are:

- The Azores Anticyclone (A_W or A_{NW}), when the isobars are at a right angle to the Straits.
- A Southwest Anticyclone, which only appears occasionally in winter, especially in January, giving rise to southwesterly winds.
- The North African Anticyclone, when its centre is displaced to the west (A_{SW}).

– The Mediterranean Low centre (C_E and C_{NE}), more frequent in winter but appearing throughout the year.
– The Peninsular and North African thermal lows, typical during the spring and winter, when their centres are moved to the east (C_E and C_{NE}).

It is very unusual to find these pressure systems isolated. Especially in summer, we can observe several pressure systems surrounding the Straits and the Peninsula; in these cases, sometimes their effects are added to each other, because they give rise to the same kind of winds –either easterlies or westerlies– but often their effects are opposite, the resultant wind depending on the local pressure gradient just at the Straits, as noted above.

DISCUSSION

As explained in the Introduction, other meteorological classifications have been proposed, but all of them refer to the entire Iberian Peninsula, and none of them was specially designed for the Straits, as ours was.

Therefore, we cannot directly compare our classification with them, but, nevertheless, we can identify some situations belonging to these classifications that correspond to some of our situations, obtaining similar frequencies.

However, our best interest lies in knowing the influence of each synoptic situation on the surface wind at the Straits.

In conclusion, as discussed above, the surface pressure distribution determines directly the surface wind characteristics. Nevertheless, the possible influence of other variables has also been evaluated, e.g. air temperature on both sides of the Straits, absolute pressure just at the measuring point, the pressure tendency, the ocean temperature on both sides of the Straits, the atmospheric stability and mixing-layer width. Of all these variables, the only one that shows a direct influence on the wind at the Straits is the air gradient temperature, although this influence is very slight, if we compare it with that of pressure distribution.

These conclusions can be very useful in attaining new objectives, such as short-term wind prediction in the Straits, on which we are working currently.

REFERENCES

Bendal A. A. 1982. Low-level flow through the Straits of Gibraltar. *Meteorological Magazine of London* 14: 149-153.
Castillo, J. M. 1981. Precipitaciones y tipos de tiempo en las Béticas-Alto Guadalquivir. *Publicación del Instituto Nacional de Meteorología* (España) A-56: 158 pp.
Scorer, R. S. 1952. Mountain-gap winds; a study of surface wind at Gibraltar. *Quarterly Journal of the Royal Meteorological Society of London* 78: 53-61.